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Technical Report UVA-12-R

PROJECT SQUID

A COOPERATIVE PROGRAM OF FUNDAMENTAL RESEARCH
AS RELATED TO JET PROPULSION
OFFICE OF NAVAL RESEARCH, DEPARTMENT OF THE NAVY

Contract Nonr 3623(00), NR-098-038

BIBLIOGRAPHY OF SQUID PUBLICATIONS

OCTOBER 1966 - MARCH 1968

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April 1968

PROJECT SQUID HEADQUARTERS
DEPARTMENT OF AEROSPACE ENGINEERING
SCHOOL OF ENGINEERING AND APPLIED SCIENCE
UNIVERSITY OF VIRGINIA
CHARLOTTESVILLE, VIRGINIA

TABLE OF CONTENTS

INTRODUCTION

The following list of Project SQUID publications represents a continuation of Project SQUID Technical Report UVA-8-R, October 1965 (AD 471 865).

This supplementary bibliography covers the period 1 October 1966 to 31 March 1968. It is arranged according to the same categories as the earlier ones with the same notation as described in the first bibliography. In summary, this bibliography is divided into six main sections, identified by Roman numerals, with subsections indicated by letters. Within each section, the order of appearance of each report is chronological for each participating organization in Project SQUID, while the organizations are listed in alphabetical order. The Project SQUID Technical Report Number consists of a prefix of capital letters followed by a numeral and a suffix of capital letters. The prefix indicates the subcontractor, the number the order of appearance, and the suffix the kind of report. The suffix R indicates a report distributed only to the Project SQUID mailing list, the letter P indicates presentation or publication at large, while the letter T indicates a thesis. When there is more than one letter in the suffix, it indicates that the same or equivalent material appeared in more than one form. An author index is provided in which reference is made by section Roman numeral, subsection letter, and subsection numeral as a continuation of the initial bibliography.

The majority of Project SQUID publications have appeared as technical papers in various scientific journals. Specific journal references are given for each of these reports when they are available. Reprints are sometines available from the authors. Government agencies and contractors may obtain full-size copies of any Project SQUID Technical Report from the Defense Documentation Center (DDC). In this connection, the DDC Identification Number (AD Number) is given, when it is available, for each entry in the bibliography. Other agencies can order copies of Project SQUID Technical Reports from the Office of Technical Services, Department of Commerce. Copies of reports may be available on a limited basis from Project SQUID Headquarters at the University of Virginia. Comments or questions regarding any Project SQUID publication may be referred to Project SQUID Headquarters, Department of Aerospace Engineering, School of Engineering and Applied Science, University of Virginia, Charlottesville, Virginia 22901.

I. PROPERTIES OF MATERIALS (TRANSPORT, STRUCTURAL)

A. GASES

No reports issued.

B. LIQUIDS

No reports issued.

C. SOLIDS

No reports issued.

II. PHYSICAL PROCESSES

A. HEAT TRANSFER

No reports issued.

B. MASS TRANSFER AND MIXING

No reports issued.

C. FLUID FLOW

116. THE EFFECT OF A STRONG LONGITUDINAL MAGNETIC FIELD ON THE FLOW OF MERCURY IN A CIRCULAR TUBE by F. W. Friam and W. H. Heiser, Massachusetts Institute of Technology, MIT-41-P, October 1967.

An experimental study of the effects of large longitudinal magnetic fields on the pipe flow of mercury has been made. The experiments were designed to provide large magnetic interaction parameters and thereby to affect profoundly transition and the level of turbulence. Two fundamental pieces of information were sought in the experiments, namely the friction factor and the transition Reynolds number as functions of the magnetic field strength. The friction factor was obtained by measuring accurately the pressure gradient along the tube. The transition Reynolds number was determined from measurements of the intermittency factor obtained using a hot-wire anemometer.

The results indicate that all relevant stability theories vastly overestimate the stabilizing effect of the field. The results also indicate that viscosity plays a critical role in reducing the friction factor of fully-developed flows. This, in turn, leads to the important conclusion that the magnetic field has an important effect on the generation of new

turbulence, as well as upon the damping of already generated turbulence.

117. SEPARATION OF GAS MIXTURES IN FREE JETS, by J. B. Anderson Princeton University, PR-113-P, April 1967. A.I. Ch. E. Journal 13, 1188 (1967). (AD 650 877)

Spatial distribution of species flux in axisymmetric free jets of helium-argon mixtures were determined experimentally. The experiments encompass the transition range between inviscid and free-molecular flow at the exits of the nozzles forming the jets. Comparison is made with existing theories of separation. The results confirm the validity of recent predictions of diffusive separation for nearly inviscid flow.

118. INTERMEDIATE ENERGY MOLECULAR BEAMS FROM FREE JETS OF MIXED GASES, by James B. Anderson, Princeton University, PR-116-P, January 1968. Entropie 18, 33-37 (1967).

Velocities and velocity distributions of species in molecular beams extracted from free jets are examined theoretically and experimentally. An extension of a nearly-inviscid flow theory is successful in predicting individual species velocities. Measurements of species velocity distributions indicate the temperature of the heavy species generally exceeds that of the light. Predictions of species velocity distributions based on source flow expansion of mixtures suggest that the velocity distributions of heavy species may be narrower than previously thought.

119. ANALYSIS OF INTENSITY AND SPEED DISTRIBUTION OF A MOLECULAR BEAM FROM A NOZZLE SOURCE by O. F. Hagena and H. S. Morton, Jr., University of Virginia, UVA-11-P, October 1966. Presented at the 5th International Rarefied Gas Dynamics Symp., Oxford, 4-8 July 1966 and published in the proceedings. (AD 800 686)

The present theoretical models to describe intensity and speed distribution in molecular beams from nozzle sources are reviewed and their respective shortcomings are discussed with close reference to the physical processes responsible for the beam formation. These processes had not been included in the theory with the result of overly optimistic predictions of intensity and thermal spread of these nozzle beams.

It is shown that inclusion of the flow divergence in front of the first aperture - called skimmer - and the temperature anisotropy predicted by kinetic theory results in appreciably lower values of intensity and modifies the velocity distribution. Even with these corrections the theories can be applied only if the skimmer interaction is avoided by keeping the skimmer Knudsen number above one, and furthermore, if the source Knudsen number is not so small as to result in a partial condensation of the beam gas.

D. MATHEMATICAL PHYSICS

No reports issued.

III. CHEMICAL PROCESSES

A. REACTION KINETICS

100. NO + O CHEMILUMINESCENT REACTION USING ADIABATICALLY EXPANDED NITRIC OXIDE by A. Fontijn and D.E. Rosner, Aero Chem, AC-6-P, January 1967. Journal of Chemical Physics 46, 3275-3276 (15 April 1967). (AD 647 778).

The rate constant for the chemiluminescent reaction NO + O $\rightarrow$ NO_2 + $h\nu$ has recently been observed to be several orders of magnitude higher for adiabatically expanded than for "normal" NO. In this note, it is shown that this enhancement can be attributed to the presence of clustered NO. These clusters allow the normal three-body excitation step to be replaced by a two-body step for which the observed rate constant is shown to be quite reasonable.

101. STEADY-STATE FIRST-ORDER REACTION AT AN INFINITE PLANE SURFACE TO WHICH REACTANT DIFFUSES FROM A POINT SOURCE, by J.A. Lordi and G.H. Markstein, Cornell University, CAL-94-P, June 1967. International Journal of Heat and Mass Transfer (in press) (AD Number not yet available).

The steady-state diffusion of reactant from a point source to an infinitely extended plane surface at which reactant is consumed by first-order reaction has been analyzed. In dimensionless form the solution depends on a single parameter that determines the relative importance of reaction and diffusion effects on the rate. An integral expression for the reactant concentration at the surface was derived and was evaluated numerically.

102. ION-MOLECULE REACTIONS IN ELECTRIC DISCHARGES, by J. L. Franklin, P. K. Ghosh, and Stanley Studneary, Rice University RICE-1-P, February 1967. ACS Meeting, Miami, April 1967. (AD 647 986).

Current knowledge available on ion-molecule reactions is reviewed in some detail. Emphasis is placed on ion-molecule reactions occurring in the ion source of a mass spectrometer and in electric discharges of various types. Consideration is given to the various types of reactions which can occur and to the experimental methods employed for establishing the reaction mechanism and rate. It is well established that many of the ion-molecule reactions which have been observed occur very rapidly with zero, or very small, activation energy. Ion-molecule reactions occurring in electric discharges can be quite different from those occurring in the ion source of a mass spectrometer, and a general description of the former reactions is not yet available. In particular, the oxygen-nitrogen system needs further study.

103. DIFFUSION AND HETEROGENEOUS REACTION X. KINETIC CONSIDERATIONS OF SURFACE REACTIONS by C. M. Ablow and H. Wise, Stanford Research Institute, SRI-24-P, January 1967. J. Chem. Phys. Vol. 9, 3424-3428, May 1967. (AD 647 979).

A theoretical analysis is presented of the influence of the kinetic order of the heterogeneous surface reaction on the diffusive mass transport of the reactant through a cylinder with catalytic walls

and catalytic end plate. Because of the relevance to experimental studies, four cases are considered: (1) a second-order reaction on the cylinder wall and a first-order reaction on the end plate, (2) a first-order reaction on the cylinder wall and a second-order reaction on the end plate, (3) second-order reactions on both the cylinder wall and the end plate, and (4) second-order reaction on the wall of a cylinder of infinite length. Examination of experimental data by means of this theoretical analysis demonstrates the prevalence of second-order recombination of hydrogen atoms on quartz under certain conditions. The second-order rate constants for this process are computed at $77^{\circ}K$ and $773^{\circ}K$.

B. THERMODYNAMICS AND THERMOCHEMISTRY

14. THE MOBILITIES OF MASS-IDENTIFIED H_3^+ AND H^+ IONS IN HYDROGEN by D. L. Albritton, T. M. Miller, D. W. Martin and E. W. McDaniel, Georgia Institute of Technology, GIT-1-P, July 1968 (To be published in the Physical Review). (AD Number not yet available.)

The drift velocities of mass-identified H_3^+ and H^+ ions in hydrogen gas at room temperature were measured. The H_3^+ ions were found to be in thermal equilibrium with the gas at E/p_o less than about 10 V/cm Torr and H^+ ions at E/p_o less than about 5 V/cm Torr. From these measurements, the reduced, zero-field mobilities were deduced: H_3^+, 11.1 ± 0.6 cm^2/V sec and H^+, 16.0 ± 0.8 cm^2/V sec. This investigation was performed with a long, low-pressure drift tube using a pulsed, time-of-flight

technique. The arrival-time histograms presented evidence of hydrogen ion-molecule reactions. It is shown that these reactions introduce no ambiguity in describing the above zero-field mobilities to single ionic species. Only a negligible fraction of the detected H_3^+ ions were formed by the three-body conversion of H^+ into H_3^+. Above an E/p_o of about 54 V/cm Torr, the disruption of H_3^+ ions contributes substantially to the H^+ signal. The reactive formation of H_5^+ from H_3^+ was evident in the H_5^+ arrival-time histograms. The zero-field mobility of potassium ions in hydrogen was also determined and the close agreement with the data of other investigators demonstrates that the apparatus is relatively free of unknown systematic uncertainties.

15. OPTICAL POTENTIAL FOR A CHEMICALLY REACTIVE SYSTEM by B. C. Eu and John Ross, Massachusetts Institute of Technology MIT-40-P, July 1967. Faraday Soc. Meeting, Toronto, September 1967. (AD Number not yet available).

The optical potential is investigated for a chemically reactive system, $K + CH_3I$, with an assumed potential of interaction among the three species, K, I, CH_3. The complex optical potential satisfies an integral equation with a kernel related to the solution of the three-body problem, as given by Faddeev. In order to obtain some information on the form of the optical potential without numerical analysis we introduce a number of approximations. The imaginary part of the optical potential, which gives rise to absorption (reactive and inelastic collisions), is with these approximations essentially a delta

function of the KI distance. The real part of the optical potential is similar in form to the repulsive potential estimated from elastic scattering experiments on this system.

16. TRANSLATION ENERGY DISTRIBUTION OF ELECTRONS AND POSITIVE IONS IN THE PLASMA OF MICROWAVE AND HIGH FREQUENCY DISCHARGES OF He, Ne, and Ar, by J. L. Franklin S.A. Sludniarz and P.K. Ghosh, Rice University, January 1968. To be published in the Journal of Applied Physics. (AD Number not yet available.)

The mean electron energy, mean positive ion energy, and sheath potentials in the plasma of microwave discharges were measured by extracting the positive ions and electrons through a small hole in a metal probe and subjecting the effused particles to a retarding electric field. The electron and positive ion translational energy distribution fitted the Maxwellian distribution function. The mean electron energy was independent of the input power to the cavity and position of visible plasma sampled along the axis of the discharge tube. The mean positive ion energy varied from a few tenths of an electron volt at high input power (100 - 30 watts) to a few electron volts at low input power. Positive ion energy profiles along the axis of the discharge tube are given. The electric field in the sheath in front of the probe orifice was mapped and approximate values of the sheath thickness were calculated from the ion production rates and the measured ion arrival rates. The variations of the sheath potential and electron density with

pressure and power input and sheath potential profiles along the axis of the discharge tube are given.

IV. COMBUSTION PHENOMENA

A. IGNITION

No reports issued.

B. FLAME PROPAGATION RATE

9. A PHALANX FLAME MODEL FOR THE COMBUSTION OF COMPOSITE SOLID PROPELLANTS, by J. B. Fenn, Princeton University, PR-114-P, April 1967. (In press in Combustion and Flame). (AD 650 868).

A new model for the combustion of composite solid propellants is developed. The flame is represented as burning at the interfacial region between streams of fuel and oxidant which are generated by vaporization of each solid component. The interface between the two solid phases receives the greatest heat flux from the reaction zone and vaporization occurs most rapidly near the interface. The reaction zone is a "phalanx" which spearheads the attack of hot reaction gases on the solid. The model provides a rational physical explanation for many qualitative observations of solid propellant combustion and successfully correlates the pressure dependence of burning rates.

C. FLAME STRUCTURE AND STABILITY

MOLECULAR BEAM ENGINEERING AT INTERMEDIATE ENERGIES by John B. Fenn, Princeton University, PR-115-P, January 1968. Entropie 18, 11-21 (1967). (AD Number not yet available).

Various methods are reviewed for generating atomic and molecular beams having energies immediately above one electron volt. In addition, mention is made of means for studying collision processes in this energy

range using beams at much higher energies which are more easily generated. The techniques covered include small angle scattering, sputter sources, merging beams, dipole acceleration, mechanical acceleration and aerodynamic acceleration. The apparent state of the art in each of these is set forth along with its relative advantages and disadvantages.

25. NEW METHODS FOR PRODUCING HIGH ENERGY MOLECULAR BEAMS by J. B. Fenn and J. B. Anderson, Princeton University, PR-117-P January 1968. (To be published). (AD Number not yet available).

Recently developed methods of generating and using molecular beams for the study of collision processes in the 1 to 20 eV range are reviewed. The methods described in detail are (1) the use of cathode sputtering to produce atomic beams, (2) the merging beams technique in which the energy difference between two collinear high energy beams is utilized, and (3) the use of supersonic jet sources.

26. MOLECULAR BEAM EXPERIMENTS IN THE LUNAR ENVIRONMENT by J. B. Anderson, J. B. Fenn and D. G. H. Marsden, Princeton University PR-118-P, January 1968. (To be published). (AD Number not yet available)

The implications of an ultra-high vacuum with the equivalent of a large pumping capacity as provided by the lunar environment are examined with respect to several kinds of molecular beam experiments. The effects of background pressure or density on beam generation, interaction with various targets and detection are considered.

Specific experiments discussed are those for measurements of (1) particle-field interactions, (2) molecule surface interactions and (3) reactive and non-reactive molecular scattering.

D. FLAME SPECTRA AND RADIATION

No reports issued.

E. MISCELLANEOUS

No reports issued.

V. ENGINES AND PROPULSIVE SYSTEMS

No reports issued.

VI. INSTRUMENTATION

A. TEMPERATURE MEASUREMENT

No reports issued.

B. PRESSURE MEASUREMENT

No reports issued.

C. MISCELLANEOUS

No reports issued.

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13. ABSTRACT

The eight supplementary bibliography covering the period 1 October 1966 to 31 March 1968 is presented. It is divided into six main sections and includes an author index. The sections are: I. Properties of Materials (Transport, Structural); II. Physical Processes; III. Chemical Processes; IV. Combustion Phenomena; V. Engines and Propulsive Systems; and VI. Instrumentation. Each entry includes title, author, affiliation, Project SQUID Technical Report Number, date, journal references (if any), AD Number (when available) and an abstract. Copies of any Project SQUID Technical Report may be obtained from the Defense Documentation Center. Comments or questions regarding any Project SQUID publication may be referred to Project SQUID Headquarters, Department of Aerospace Engineering, School of Engineering and Applied Science, University of Virginia, Charlottesville, Virginia, 22901.

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